4500
FS-22-PSW-2

Berkeley, California
March 12, 1963

Progress Report

INSECTS DESTRUCTIVE TO WOOD

1962 Studies

By

Boyd E. Wickman, Entomologist

NOT FOR PUBLICATION

U. S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE
PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION

TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	2
RADIOGRAPHIC TECHNIQUES	2
Machine Calibration	3
Studying Insect Development by Periodic Radiographs	5
Stereoradiography for Measuring Wood Borer Damage	9
Accuracy of Radiographs for Detecting Wood Borers	9
Natural Mortality of Siricids	11
REARING TECHNIQUES FOR WOOD BORERS	12
Cages	12
Sandwich Boards	13
Trap Logs	13
Insects Collected	13
SAMPLING FIRE-DAMAGED STANDS	16
Going Fire	16
One-Year-Old Burn	17
Two-Year-Old Burn	17
NOTES ON SIRICID BIOLOGY	18
Life Cycles	19
Sex Ratios	19
Damage	19
Parasites and Predators	20
LITERATURE CITED	21
APPENDIX	23

U. S. DEPARTMENT OF AGRICULTURE - FOREST SERVICE
PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION
Forest Insect Research

Progress Report

INSECTS DESTRUCTIVE TO WOOD

1962 Studies

By

Boyd E. Wickman, Entomologist

SUMMARY

Research on insects destructive to wood was started in 1962. The studies were exploratory and intended to provide a basis for developing long-term research plans to answer specific questions such as: the insects involved, the damage they do, their life histories and methods of control.

1. Field work was conducted at the Hat Creek Field Laboratory, where a dental X-ray machine was installed. This machine did not prove to be suitable for producing satisfactory radiographs of thin biological specimens because of high kilovoltage.

2. A series of radiographs were taken of siricids in boards for a 9-month period. Development from last-instar larvae to adults varied from a low of 24 days to a high of 206 days. The X-radiation had no apparent detrimental effects on the insects. Roentgenography appears to be a practical and efficient technique for studying wood-boring insects without destroying their natural habitat.

3. Stereoradiography techniques were explored with a wheatstone medical-type stereoscope. Results were not satisfactory.

4. Correlation coefficients obtained from comparisons of radiographs and dissections of infested boards to find siricids were very high ($r = .98$). The radiographic technique was more accurate, about six times faster, and 1/3 the cost of dissection.

5. Natural mortality of siricids in rearings and tests was 34 percent.

6. Different types of cages and rearing techniques were checked for wood borers. The rectangular screened cage with a glass door was most convenient. Several <u>Ergates</u> larvae were successfully reared from a sandwich board arrangement. Trap logs attracted some wood borer adults in the early summer. Twenty-two different species of wood-boring insects were reared or collected.

7. Three different aged burns (going fire, 1-year-old, and 2-year-old) were visited and sampled for destructive insects. The information was collected on IBM data forms for later card punching and analysis.

8. Siricids family proved to be the most prevalent wood-boring insects present in the studies. Therefore this was the test insect for most experiments. In the process new biological records were obtained for several California species.

INTRODUCTION

This report covers research work during the calendar year 1962 on insects destructive to wood. Since this work has just been started, the studies reported here are preliminary in nature as indicated in the study plan for the 1962 season.[1/] The objectives of the studies are to determine what insects attack damaged or recently killed trees, how soon they infest these trees, how much damage they do, how long they remain in the wood, their life histories, how the insects are affected by environmental factors; and to devise and test methods for preventing or controlling their attacks. The information obtained from this study is intended to help provide a basis for developing long-term plans for more intensive research on wood borers.

Most of the work reported here was done at the Hat Creek Field Laboratory maintained by the Forest Service, U. S. Department of Agriculture. Cooperation from several other agencies and ~~private companies helped facilitate~~ the research. The Department of Entomology and Parasitology, University of California, Berkeley, made available X-ray machine and darkroom facilities for some of the work. Dr. Howell Daly of that department did some of the wood dissection work in conjunction with his studies of siricids. The University of California School of Dentistry trained the author in roentgenography. Hughes Brothers Lumber Company, Foresthill, California, provided siricid-infested lumber and logs from the Volcano Burn. The National Forest Administration provided study sites. The assistance of Charles Sartwell, Jr., in the research program is also gratefully acknowledged.

RADIOGRAPHIC TECHNIQUES

Berryman and Stark (1962) and Johnson and Molatore (1961) have discussed the principles and described the techniques involved in radiographing forest insects. These authors show that kilovoltages in the 20-40 range give the most satisfactory results for studies of bark beetles in bark and wood borers in 2-inch to 3-inch lumber. Kilovoltage supplied to the tube affects the wavelength or penetrating power of the X-ray beam. The

---

1/ Study Plan, 1962 season, Insects destructive to wood, May 7, 1962, by Boyd E. Wickman. 4 pp., typewritten.

higher the kilovoltage the higher proportion of shortwave length X-rays or "hard radiation." When the kilovoltage is too high the subject is completely penetrated, resulting in lack of shadow image on the X-ray film. With the kilovoltage too low there is not enough X-ray penetration of surrounding tissues to produce an image. The ideal situation is to provide the proper radiation so that a pattern is produced giving an image of the subject that is lifelike. This effect of kilovoltage on subject contrast is the most important variable of the radiographic technique (Eastman Kodak Company, 1960).

Other variables include quantity of radiation, which at any particular kilovoltage is proportional to the tube current (milliamperes) and time of exposure. These two are often combined as milliampere-seconds (MaS). The density of the finished film depends upon exposure. And the quantity of radiation reaching the film is dependent on the focus-film distance (FFD). Usually maximum FFD produces the sharpest image.

MACHINE CALIBRATION

A military surplus Profexray dental X-ray machine was installed at Hat Creek in May 1962 for use in studying wood-boring insects. This machine is designed to operate at 60 kilovolts peak (KvP) and 10 milliamperes. The period of exposure, in seconds, and target film distance, are the only adjustable controls. Different types of film were screened for usefulness in this type of work in February under the guidance of Dr. Gordon Fitzgerald, School of Dentistry, University of California Medical Center. The following Kodak films were tried on 2-inch thick wood infested with siricids: Industrial Type AA in ready packs, Industrial Type M in ready packs and film holders, Medical No Screen, and High Speed Dental Occlusal. Industrial Type AA was the most satisfactory in this test.

Tests were made to calibrate the machine for use on different materials (seeds, bark, and wood), different thicknesses of wood, and different cuts (tangential and radial sections). Table 1 summarizes the tests. Kodak Industrial Type AA X-ray film in ready packs 8 x 10 inches was used for all radiographs. Radiographs were examined and compared on an X-ray illuminator and selected wood samples were dissected to check the accuracy of interpretation. Notes were kept on each radiograph to reference future work.

Table 1.--Insect infested samples tested with Profexray unit

Infested sample	Tests	Thickness	Moisture content	Insect
	Number	Inches	Percent	
Douglas-fir seed	6	3/16	>50	Douglas-fir seed chalcid
Jeffrey pine stem	10	$\frac{1}{4}$-2	>75	Pine reproduction weevil
Ponderosa pine bark	12	1-1 3/4	<20	Western pine beetle
White fir boards	12	2	1/ 12-95	Siricids
Incense-cedar radial discs	6	4, 9, 12	<20	Siricids

1/ Calculated by oven drying, the rest estimated.

Results

1. The machine did not give satisfactory radiographs for interpreting western pine beetle populations in bark, finding seed chalcids in Douglas-fir seeds, or locating pine reproduction weevil in $\frac{1}{4}$-to 2-inch stems. All the radiographs produced had very poor contrast and detail due to the high KvP of the machine.

2. Fairly good radiographs were obtained of siricid-infested incense-cedar bolts up to 12 inches thick. Sharpest definition was obtained, however, with samples 2 inches to 4 inches thick.

3. Both cuts of infested wood, tangential and radial, were easily radiographed with moisture contents up to 75 percent. Highest quality radiographs were obtained when moisture content was 20 percent or lower. Most difficulty was experienced when the wood samples had some areas with very high moisture content. More work is needed with wood containing moisture contents higher than 75 percent.

4. Closeness of grain is also a limiting factor with radiographs. However, with coniferous softwoods no difficulties were experienced from grain, except around knots.

Discussion

A dental X-ray machine such as the Profexray unit does have some serious drawbacks for use in biological studies because of its relatively high KvP (60) and the lack of kilovoltage control. To complicate matters last summer the electrical system at Hat Creek could not provide steady current to the machine. Since KvP is dependent on incoming voltage, power fluctuations resulted in a range of kilovoltages during X-ray exposures even though the machine is set at 60 KvP. This deficiency is being corrected by modernization of the electrical system at Hat Creek.

The results showed that 60 KvP are too high for obtaining good contrast radiographs of thin bark, twig, seed, wood, and insect specimens. This limits the machine primarily to X-ray of wood sections, and will preclude more refined work such as studies on the digestive processes of wood borers, until a more versatile machine is obtained. However, on the plus side, the machine's high kilovoltage did produce penetration and readable radiographs of wood blocks up to 12 inches thick. This can be of great value for studying wood-boring insects.

STUDYING INSECT DEVELOPMENT BY PERIODIC RADIOGRAPHS

Fisher and Tasker (1940) pioneered the use of X-rays for detecting the presence of wood-boring insects in timber. They studied both hard and softwoods containing a variety of wood-boring pests. They analyzed very completely wood thickness in relation to insect size and kilovoltage needed for proper contrast, using samples ranging in thickness from $\frac{1}{2}$ to 5 inches. In the course of their work they did follow the development of two deathwatch beetle larvae for a period of 3 months, primarily in relation to the total linear movements of the larvae in the wood. And they suggested that radiographs taken at intervals could provide an excellent method of studying the development of wood-boring insects.

Oliver (1959) used X-rays to detect and study marine wood borer damage. And Berryman and Stark (1962) suggested that X-rays could be of great value for studying life histories of cryptic insects. The main benefits of using X-rays to study the development of such insects are: (1) The insect's natural habitat does not have to be disturbed during the course of the studies; and (2) changes in development are permanently recorded on film.

One of the primary objectives of this year's studies was to explore the use of X-rays for studying wood borer development. White fir and incense-cedar boards 6 3/4 x 10 x 2 inches in size, with at least several siricid larvae present, were selected for the study. The white fir came from the Donner Ridge Burn, and was milled and collected on October 15, 1961. The larvae then were mostly in the last instar in their prepupal chambers. Radiographs of this material were taken at 2-week intervals, starting on February 16. In July the interval of radiography was shortened to 1 week and later in August to 4 days.

The incense-cedar boards came from the Volcano Burn. The logs were cut in October 1961 and milled in March 1962 when samples were collected for the study. The insects were mostly last-instar larvae when collected. All radiographs start from last-instar larvae since initial date of attack was unknown. Radiography started on July 23 and was continued weekly. The moisture content of the wood was estimated at 95-150 percent when the samples were first collected, but this declined to 10 percent when emergence was complete. The samples were caged individually and when the adults emerged they were collected for identification. All but one of the samples were held under identical conditions in an outdoor

insectary. This sample containing one male was placed in an incubator, 78° F., and 20 percent relative humidity from August 7 until emergence on September 30.

Results

Figure 1 shows the development of a series of Sirex longicauda Middk. and Sirex areolatus (Cress.) radiographed periodically from February 16 through October 30. Development from last-instar larvae to adults varied from a low of 24 days to a high of 206 days.

Our study showed a wide range in the period required for last-instar larvae to develop (assuming eggs were laid about the same time), and a wide range of pupal periods. S. longicauda had the most consistent development, with three pupae maturing almost identically in 40 days. The fourth pupa was incubated and it matured in 28 days. Prior to incubation this insect had the slowest development of all the S. longicauda. Nine S. areolatus had pupal periods of 10 to 97 days, with no consistent pattern of development evident. The insects in sample No. 3 showed shorter overall development periods because radiographs were not started until July 23 when larval development was almost finished.

It took 5 to 10 days for the new adults of both species to harden and chew their way out of the board.

Several Serropalpus barbatus (Schall.) larvae were present in sample No. 3, and their development was very closely attuned to the siricids. Pupal periods were about the same, and adults emerged at the same time.

All the development periods are approximate. By extrapolation from weekly radiographs they can be placed within 3 or 4 days, and from the 4-day schedule down to a 2-day estimate. The only way to avoid this estimation would be daily radiography. This might subject the insects to a dose which would affect their development and would also be quite expensive. The dose they received did not affect their development timing according to emergence from unradiographed samples.

Discussion

Periodic radiography is a practical and efficient method of following the development of wood borers. The main shortcoming of this study was the unknown egg-laying dates of the species studied. The milling date of the lumber was known and most of the larvae were fully grown at that time. Assuming the larvae took at least a year to mature (Middlekauff, 1960), the egg laying probably occurred from August to October 1960. Unfortunately, there have been no biological studies of California siricids, but it appears from this work and field observations that both S. longicauda and S. areolatus can have 1-year and 2-year life cycles. Hanson (1939) reports that S. cyaneus Fab., a closely related species, normally has a 3-year life cycle in England. The life cycle in California is unknown.

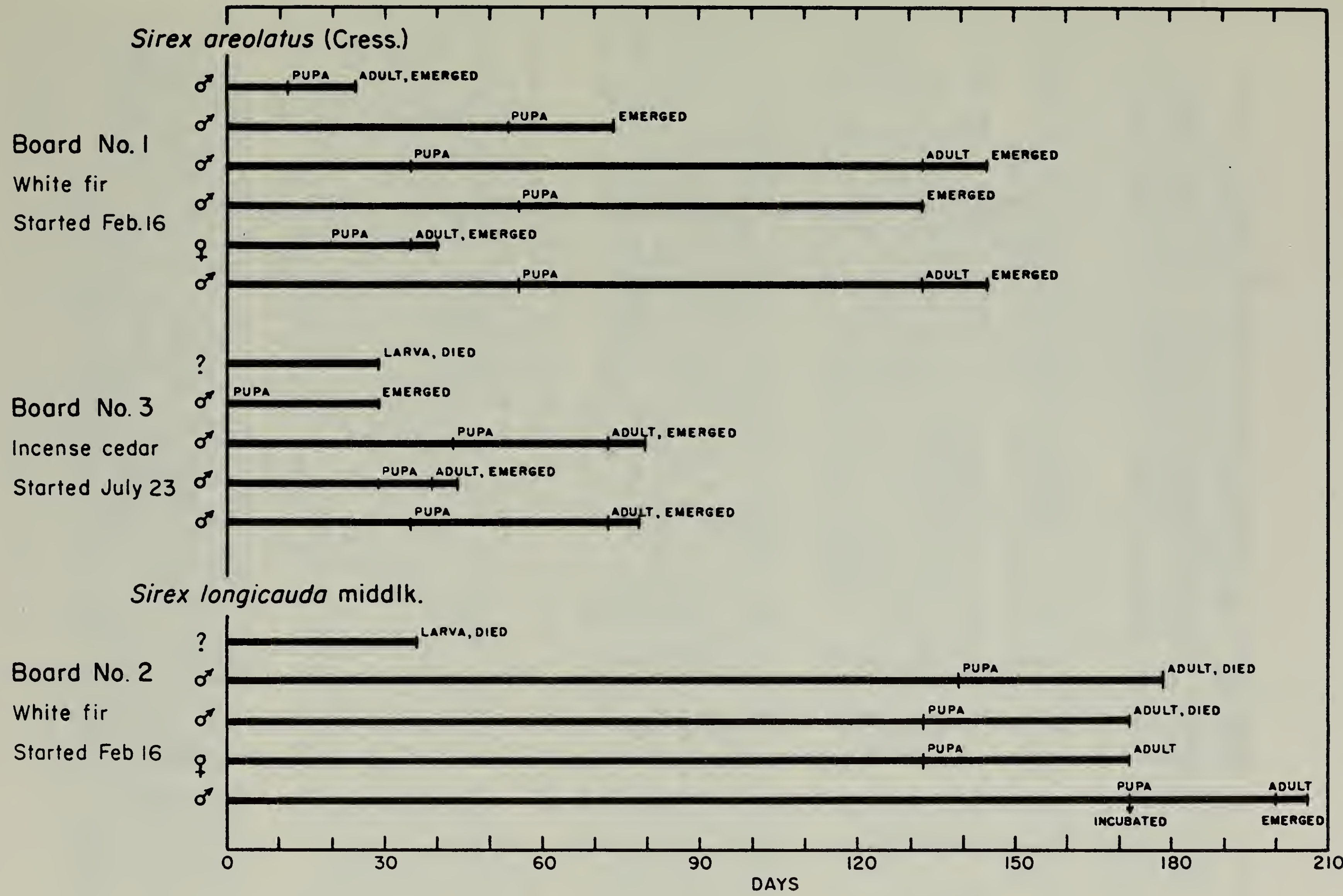

Figure 1.--Development of siricids in white fir and incense-cedar lumber as determined by radiographs.

It is known that large doses of X-radiation can cause serious biological damage to living organisms. Though insects are not as susceptible to irradiation as mammals, the measurement and effect of sublethal doses should be considered. The doses received by siricids in this test were roughly estimated because instruments were not available to make exact measurements.

Bletchly (1961) exposed different stages of several wood borers to various doses of gamma-radiation which is very similar to X-radiation. He found that a single dose of 4,000 roentgens (r) to larvae of Lyctus and Xestobium produced a proportion of adults with deformed elytra. Radiation doses of 5,800 r to 6,500 r killed Xestobium or prevented them from emerging. Most of the death seemed to occur during moulting or during the pupal stage. Periodic X-radiation in low doses such as the siricids received does not have nearly as deleterious an effect as a single massive dose because of damaged cell recovery between exposures. Radiographs of the siricids can be likened to dental and medical radiography for humans.

It is difficult to measure the effects of doses of low-level radiation on wood borers because of the attenuation of the X-ray beam caused by the wood. This is dependent, according to Badun (1959), upon the density, moisture content, and thickness of the wood under study. Bletchly (1961) showed that attenuation in Scotch pine blocks 40 cm. thick was about 50 percent, and that the relationship between block thickness and percentage dose received was roughly linear. Also the radiation intensity at the fringe of the beam is half that at the center.

The radiation received by the siricids in our studies can be approximated by estimation. The air dose of X-radiation emitted by the particular machine used has not been measured yet, but from similar machines, it is estimated to be between 50-100 r per minute at 24 inches FFD. If we assume that Scotch pine and white fir wood attenuate X-radiation similarly, a 2-inch thick white fir board has an estimated 6-10 percent attenuation. So a 4-second exposure at 24 inches would equal 6.7 r, minus 10 percent attenuation, for a total of 6 r dose for each exposure (calculated at the probably high dose rate of 100 r/minute). The estimated total maximum dose over a 210-day period for the slowest developing insect was 150 r. However, most insects received total doses between 75 and 100 r. The lethal threshold of irradiated siricid larvae is not known, but other wood-boring larvae can stand 5,000 to 10,000 r; and doses greater than 72,000 r were needed to prevent emergence of Lyctus when the adult stage had been reached (Bletchly, 1961). From what we know at this time the effects of a total dose of 100 r from 20-30 exposures spread over several months should be insignificant. However, studies are needed to evaluate the biological effects of low level X-radiation on wood borers.

STEREORADIOGRAPHY FOR MEASURING WOOD BORER DAMAGE

Stereoradiography has wide application in medicine, and it has been tried in at least one invertebrate study. Crisp. et al. (1953) used it for examining shipworm infestations. He achieved a striking three-dimension effect in radiographs of the burrow arrangement in wood blocks $\frac{1}{2}$ to 1 inch thick, using a wheatstone stereoscope. This technique would be very valuable for identifying insects in wood and for measuring the amount of damage they do more accurately than is possible otherwise.

A wheatstone, medical-type stereoscope was obtained from military surplus and used with paired 8-by 10-inch radiographs. Wood samples radiographed varied in thickness from 2 to 12 inches. The samples were infested with siricid larvae, 1 to 1.5 inches long. The tube shift was 3 and 3/16 inches for a focus film distance of 30 inches at an eye radiograph distance of 25 inches. (Eastman Kodak Company, 1960, p. 47.)

The stereoradiographs did not prove satisfactory, probably because of faulty technique. Radiographs with sharpest definition were of wood blocks only 2 inches thick, while in those of thicker samples (8 to 12 inches) the definition was poor, making it difficult to achieve third dimension. More work is needed with the wheatstone stereoscope to perfect the technique for using it in studying wood borers. The possibilities of table top mirror stereoscopes used on the illuminator should be investigated also. The latter instrument is much more compact and easy to use.

ACCURACY OF RADIOGRAPHS FOR DETECTING WOOD BORERS

It was not known whether borers in wood could be located more accurately by dissection or by radiograph methods. Berryman (1961) and DeMars (1962) found that the two methods produced results that were closely correlated in studying western pine beetle broods in bark. They concluded that X-ray interpretation was more accurate than dissection. To see whether this was true for wood borers, two series of 20 white fir boards $6\frac{1}{2}$ x 10 x 2 inches in size, and infested with <u>Sirex longicauda</u> were radiographed in November with the University of California Picker X-ray unit. The dissections were done by separate workers.

The number of siricid larvae, pupae, and adults, and other insects alive and dead was recorded for each sample and for both methods. The first 20 samples were dissected without any reference to the radiographs. The information obtained is shown in table A (Appendix). The second group of 20 samples was dissected with the help of radiographs immediately after they were taken. Interpretation of this set was then done 10 days later, without knowledge of the dissection results, shown in table B (Appendix). Correlation coefficients were then calculated for the two methods of estimating brood density. The formula used was:

$$Rxy = \frac{\Sigma xy - \frac{(\Sigma x)(\Sigma y)}{N}}{\sqrt{[\Sigma x^2 - \frac{(\Sigma x)^2}{N}][\Sigma y^2 - \frac{(\Sigma y)^2}{N}]}}$$

Where x = radiographic estimate of number of insects, y = dissection estimate of number of insects and Rxy = the correlation of x to y.

Results

The estimates of siricids in white fir obtained by the two methods were closely correlated. (See table 2.) The first set of correlation

Table 2.--Correlation coefficients for radiographic and dissection methods of estimating siricid broods in white fir lumber

	Dissections independent of radiographs		Dissections based on radiographs	
	Larvae	Total brood	Larvae	Total brood
Live	.8218	.8660	.9802	.9032
Dead	1/ 1.000	1/ 1.000	1/ ____	1/ ____
Live + dead	.7924	.8381	.9756	.9803

For 18 degrees of freedom : r at 5 percent = .444
r at 1 percent = .561

1/ Sample too small for significance.

coefficients calculated from the data obtained from radiographs and from dissection done independently shows a significant correlation for all counts. The counts from dissections were consistently lower than the ones from radiographs, but the correlation coefficient .8381 for total brood live and dead is reasonably good.

The second set of correlation coefficients calculated from the data obtained by using the radiographs to guide dissection shows a very high correlation, as would be expected. The ability of a person to find more siricids during dissections by referring to radiographs demonstrates their superiority over a straight dissecting technique.

Time comparisons for the two methods also favor the radiographs. Radiographing 20 boards took 30 minutes, developing the film 30 minutes, and interpretation 60 minutes, for a total of 2 hours. Dissection of 20 samples without the aid of radiographs took approximately 14 hours, and even when radiographs were used it took 7 hours. Radiographic costs are $.27 per sheet of film, $.05 per radiograph developing chemicals, and $.02 X-ray machine depreciation cost per exposure, for a total of $.34 per sample. If labor costs per hour are considered equal (say $3.00 per hour), then each sample cost $.64 using radiographic interpretation or $2.10 using the dissection method. The radiographic method thus is not only more accurate than dissection for obtaining estimates of siricids in wood, but it is faster and cheaper.

Discussion

Actually radiographic interpretation by itself gives accurate enough results for use in determining siricid infestations in lumber. The insects are large enough to preclude serious image interpretation error. The lowest value for Rxy .9032 for total live brood from table B (Appendix) shows the principal weakness in radiographic interpretation; namely, the tendency to classify recently dead brood as alive because there is no differentiation on the radiograph. This same problem plagued DeMars, Berryman and Stark, and others when doing radiographic counts of infestations. However, unexpected mortality rarely reaches a level where this is a serious deterrent to the radiographic method. Further study of this method as a tool for studying other wood-boring insects seems warranted.

NATURAL MORTALITY OF SIRICIDS

Mortality of siricid, larvae, pupae, and adults showing up on the radiographs and found during dissections of white fir and incense-cedar lumber was sometimes quite high (table 3). In the dissected samples 34 percent

Table 3.--Siricid mortality found during board dissection in 1962

	Larvae	Pupae	Adults	Total
Alive	66	3	1	70
Dead	14	6	16	36
Total	80	9	17	106
Percent mortality	17.5	66.6	94.1	34.0

of the insects were dead. The possibility that this mortality might be due to X-radiation was checked by dissecting unradiographed boards in the insectary and logs in the woods to look for dead siricids. This was done between February and November 1962. Mortality in samples from these sources was also high, but the amount was not determined exactly because some emergence had taken place so that the natural population was unknown.

The results from the dissections of radiographed samples are probably representative of what is occurring in the natural habitat, though possibly not in the ratios given in table 3.

REARING TECHNIQUES FOR WOOD BORERS

Peterson (1937) describes cages and rearing techniques used for wood-boring insects by other workers. Most of the past rearing has been done by caging infested logs or placing individual larvae in vials packed with sawdust. The cages were made of sheet metal or wood with a collecting jar at a light source, or of various screened designs. All three types reportedly worked satisfactorily.

Last summer several types of cages on hand were checked for rearing wood borers in logs and lumber, and rearing larvae between sandwiched boards. Very small tests were also made of freshly felled trees for trap logs to check on the attractiveness of such material and also obtain a supply of wood borers for other tests.

CAGES

Three types of cages were tried, all approximately of the same dimensions, 16 x 16 x 24 inches high. One type was made of wood with a glass collecting jar; one type was cardboard with a glass collection jar; and the third type was screen with a removable glass door. Lumber and bolts of pine, fir, and cedar infested with cerambycids, buprestids, and siricids were placed in the cages for rearing. The screen cages were the most satisfactory because the material could be easily observed for insect emergence, and removed periodically for radiographic work.

Difficulties were encountered with the solid wood cages. When moist samples were used there was a tendency for mold to develop to the detriment of the insect brood. Also _Serropalpus barbatus_ adults were not always attracted to light and thus could not be collected in the jars. The main drawback to cardboard cages was the ease with which _Monochamus maculosus_ Hald. chewed their way out of the cage after emerging from their host.

SANDWICH BOARDS

Chambers were chiseled between 2-inch thick boards to receive *Ergates spiculatus* Lec. larvae in a sandwich arrangement. This system worked well and provided easy access to the larvae to study development and to take photographs.

A full-grown larva was started in white fir on February 15, 1962, and reared to adulthood on August 3. Two more full-grown larvae were started in August and were still alive on October 15.

TRAP LOGS

Two sets of trap logs were established at Hat Creek during the summer to see what insects would attack them. An 8-inch diameter incense-cedar tree was cut into 4-foot bolts in early June and left in the open. A second set of ponderosa pine bolts, 8 inches in diameter and 4 feet long, were cut in mid-August and exposed for attacks. Some of the pine logs were partially coated by strips and spirals of tanglefoot, with two logs left uncoated.

The cedar logs received numerous attacks by a cerambycid, probably *Semanotus ligneus* (Fabr.), which have resulted in a plentiful brood of larvae. No wood-boring adults were caught in the tanglefoot on the late-summer pine logs, or have larvae been found under the bark of the uncoated logs. During the summer of 1962 more wood-boring insects were found flying during the month of June than the months of July, August, or September.

INSECTS COLLECTED

Insects from fire-damaged conifers reared at Hat Creek were collected throughout the summer. Additional material was captured in flight on burns or in flight or at lights at Hat Creek. Much of the material (table 4) has been determined tentatively and placed in the Hopkin's collection. Species which have not been previously reported in association with fire-killed timber have been sent to taxonomists at the National Museum for identification.

Table 4.--Insects collected on burns or reared from wood, 1962 season

A. Wood Borers	Source
Coleoptera	
Buprestidae	
Buprestis aurulenta L.	*Libocedrus decurrens* & Flight (burn)
Chalcophora angulicollis (Lec.)	Flight (burn)
Chrysobothris sp.[1/]	Flight (burn) and ovipositing on dead *Pinus ponderosa* in burn
Melanophila gentilis Lec.	Flight (burn)
Melanophila consputa Lec.	*Pinus ponderosa*, Flight (burn)
Melanophila acuminata (DeG.)	*Pinus ponderosa*, Flight (burn)
Cerambycidae	
Ergates spiculatus Lec.	*Pinus ponderosa*, *Abies concolor*
Prionus californicus Mots.	Flight (light)
Tragosoma depsarium (L.)	Flight (light)
Monochamus maculosus Hald.	*Pinus ponderosa*
Centrodera spurca (Lec.)	Flight (light)
Acanthocinus spectabilis (Lec.)	*Pinus ponderosa*
Asemum caseyi Lins.	*Pinus jeffreyi* (killed by Jeffrey pine beetle)
Spondylis upiformis Mann.	Flight (Hat Creek, daytime)
Arhopalus asperatus (Lec.)	On *Pinus ponderosa* and *P. jeffreyi* at a new burn
Semanotus ligneus (Fabr.)	*Libocedrus decurrens* (burns and trap logs)
Semanotus amethystinus (Lec.)	*Libocedrus decurrens*, Flight (burn)
Melandryidae	
Serropalpus barbatus (Schall.)	*Libocedrus decurrens*, *Abies concolor*

Table 4 continued.

A. Wood Borers (continued)	Source
Hymenoptera	
Siricidae	
Sirex areolatus (Cress.)	*Abies concolor*, *Libocedrus decurrens*
Sirex longicauda Middlk.	*Abies concolor*, *Libocedrus decurrens*
Xeris morrisoni (Cress.)	*Abies concolor*
Syntexidae	
Syntexis libocedrii Roh.	*Libocedrus decurrens*
B. Parasites and Predators	
Coleoptera	
Ostomatidae	
Temnochila virescens (Fabr.)	(Associated with buprestids and cerambycids under bark)
Diptera	
Asilidae	
Laphria sp.1/	(Associated with buprestids and cerambycids under bark)
Hymenoptera	
Ibaliidae	
Ibalia ensiger Norton1/	*Sirex areolatus* and *S. longicauda*, Flight (lumberyard)

1/ Tentative determination.

SAMPLING FIRE-DAMAGED STANDS

Studies of fire-damaged stands should yield considerable information about the insects that attack different types of host material, the conditions favorable for attacks, and possible approaches to control. Consequently, we had planned to sample during the course of the summer three stands that had been burned at different times. Because of travel limitations, only two burned stands were sampled, one currently burning, and one burned a year ago. However, later in the fall two stands burned 2 years ago were briefly visited.

The objectives of field examination of burns were to collect data on burn severity and insect species attracted, and to study ecological conditions; then relate this information to insects collected and wood borer damage found. To facilitate data collection and correlation of insects to type of burn, records were collected on an IBM data processing form (Appendix). With this form information for each insect is punched on an individual card from the data collection form. Burn information is gang punched for each series of insects taken from one burn. Not enough records have been collected yet to make the data meaningful, but after several years the accumulation should be enough to run an analysis and see what relationships exist.

Neither of the burned stands sampled in the summer of 1962 were ideal from the standpoint of timber type, size, and stand density, but some interesting observation records were obtained. The most productive areas sampled from the standpoint of insect material found were two large 1960 burns in the central Sierra.

Notes on each of the three age classes of burn follow.

GOING FIRE

A 30-acre fire in pine and brush near Hat Creek was sampled while fire fighting on July 25. At dawn (5 a.m.) that day, large numbers of *Arhopalus asperatus* (Lec.) were flying to several badly scorched ponderosa and Jeffrey pines. The fire was still smoking and the bark was warm and charred. The beetles were observed mostly on the basal 3 feet of the trees. Several pairs were mating and other adults appeared to be seeking oviposition sites. It is not known how much lumber degrade this species can cause in fire-killed pine, but from the numbers attracted to this fire it could cause serious problems. The use of smoke for an attractant and the sampling of burning forest fires seems like a most productive study site to obtain initial attack information. Linsley (1933) and Gardiner (1957) and others have reported large numbers of wood-boring insects attracted to smoke.

ONE-YEAR-OLD BURN

A 40-acre stand of second-growth ponderosa pine and incense-cedar at Montgomery Creek (elevation 2,000 feet) burned in August 1961 was sampled in early June 1962. Borer-infested logs were cut and taken to Hat Creek for rearing. These logs produced many different insects; however, buprestids were the most common. Collections were also made in June 1962 of a wide variety of wood borer adults on the wing and several attacking scorched, dead trees. (See table 4.) An asilid fly, which may be an important predator of wood borers, was found closely associated with wood borer larvae under the bark of pine.

It appears that even small one-year-old burns provide plenty of infested timber, and if sampled at the right time can give invaluable information on the emergence dates of wood borers with a 1-year life cycle.

TWO-YEAR-OLD BURN

Fire in August 1960 killed or injured large amounts of timber on two 45,000-acre areas now known as the Donner Ridge and Volcano Burns. Several million board feet of true fir, pines, and incense-cedar were salvaged from each of these burns. In September 1961 mill owners handling this material reported that large white grubs were causing serious lumber degrade in all species of wood. Some lumber shipments sent to the east coast at that time were rejected and returned because of insect damage. The insects involved proved to be several species of the siricid family, and emergence of the adults from lumber piles and log decks during the latter part of September and the first week of October 1961 at times reached spectacular proportions. True firs and incense-cedar were most heavily infested, but sugar and ponderosa pines were not immune.

According to Middlekauff (1962) the siricid larvae may complete their life cycle in cut lumber, and where infested lumber has been used in home construction, the adults may emerge a year or more after the home has been completed. According to rearing records and observations, as well as reports from other sources, this is indeed the case.

Attempts to control the borers by fumigating stacked lumber with methyl bromide, either under plastic tarpaulins or in boxcars, reportedly failed. Dipping lumber off the green chain in a 5 percent water emulsion of BHC also is reported to have been unsuccessful for killing the well protected larvae in the wood. Because of the low value of fire-damaged fir and cedar, kiln-drying the lumber to control insects is uneconomical. However, operators that did kiln dry all infested lumber under their normal kiln-operating schedules of 140°-160° F. for 24 hours (lumber stickered) reported no repercussions from purchasers.

Reports that the kiln treatment did not kill the siricid larvae immediately were checked in the fall of 1962. The material studied was obtained from a mill at Truckee in October, and consisted of fir from the Donner Burn, salvaged in August 1962. The logs were milled in early October, and units of 2-inch dimension stock were kiln-dried on October 16 for 24 hours at 150° F. The lumber was then put through the planing mill on October 18 where samples were collected.

On October 20, two boards 12 x 12 x 2 inches were dissected at Lafayette. On November 3, five boards 12 x 12 x 2 inches were dissected after being held outdoors in partial shade and mild weather at Lafayette. The results of dissection are shown in table 5.

Table 5.--Mortality of siricids in white fir boards after normal kiln drying schedules

	Larvae		Pupae		Other wood borers	
	Alive	Dead	Alive	Dead	Alive	Dead
Oct. 20	1/ 3	1	1	0	0	0
Nov. 3	0	24	0	2	0	2
Total	0	28	0	3	0	2

1/ Live insects were held in a petri dish. The pupa died 2 days later and all three larvae died over a period of 2-5 days.

These findings by no means prove that kiln drying under regular schedules produces 100 percent mortality of siricids, especially since some larvae remained alive for 9 days after treatment. On the other hand it is not known if regular drying schedules were followed in the treatment of the lumber studied, since the kiln treatment was not under experimental control. Controlled tests would help to answer these questions.

NOTES ON SIRICID BIOLOGY

Very little is known about the life history and habits of California siricids. Females ovipositing in logs, stumps, and dying trees have long been a familiar sight to woodsmen. But a large convenient population has not been available for study until the 1959 and 1960 fires in California. As mentioned earlier, siricids were so numerous that they were the main problem of the salvage program.

Though no specific life history studies were started last year, biological information was gathered in conjunction with the other studies and by field observation. Information on life cycles, sex ratio, damage, and parasites and predators follows.

LIFE CYCLES

The Donner and Volcano fires occurred in late August 1960. Emergence of siricids from fire-killed trees utilized for lumber occurred in September and October 1961. Dr. Middlekauff of the University of California identified the siricids as *Sirex cyaneus*, *S. areolatus*, and *S. longicauda*. This means that at least these three species could have a 1-year life cycle. Hanson (1939) reports *S. cyaneus* has a 3-year life cycle in England. Infested lumber collected from the Donner Burn in October 1961, which was attacked in the fall of 1960, produced *S. areolatus* and *S. longicauda* all during the summer and fall of 1962, and some boards contained larvae in late fall. So at least these two species have 1-, 2-, and possibly 3-year life cycles within homogeneous populations held under similar conditions.

SEX RATIOS

The sex ratio of all siricids (127 males and 61 females) collected to date from rearings and field collections is 2:1 (males to female).

Broken down by species as follows:

Sirex areolatus	44 females, 115 males
S. longicauda	12 females, 11 males
Xeris morrisoni	1 female, 1 male
Syntexis libocedrii	4 females, 0 male

This does not agree with the reports of others who have mentioned the scarcity of siricid males (Middlekauff, 1960). Chrystal (1928) notes that the sex ratio of *S. cyaneus* is 2:1 females to male. However, *S. areolatus* is the species with the preponderance of males collected during this study. Since this insect has not been studied before this may, in fact, be its sex ratio, but much more information is needed before this can be claimed. There are also indications that eggs from unfertilized females give rise to males only (Rawlings, 1951).

DAMAGE

Gallery length seemed to be proportional to the size of the insect. The smaller the larvae the shorter linear distance of boring. Five boring tunnels of *Sirex areolatus* larvae estimated from radiographs measured 4.0 inches, 5.0 inches, 6.5 inches, and 7.5 inches. However, boring tunnels of the early-instar larvae were too small to detect. Volume measurement seems more reliable than the linear method for determining

the amount of wood destroyed by most wood borers. Wilson (1962) filled galleries with modeling clay, converted the weight of clay needed to fill a gallery to volume, and used this to represent the wood destroyed by boring. Two average-sized S. areolatus galleries were filled with modeling clay. One gallery had a volume of 1.5 cc., the other 2.0 cc. Wilson (1962) estimated that 3 cc. of wood are lost per Urocerus boring. This agrees quite well since Urocerus is a larger insect on the average. More work is needed along this line.

PARASITES AND PREDATORS

An endoparasite of siricids, probably Ibalia ensiger Norton, was very numerous at the Volcano Burn on September 27.

They were flying around stickered stacks of incense-cedar lumber of 2-inch dimension, infested with Sirex areolatus at Hughes Brothers Mill, Foresthill. The material was logged in May 1962 and milled in August 1962, then brought to the Foresthill Mill for kiln treatment and planing. Between 10 a.m. and 12 noon on September 27 many parasites were flying around the stacks and resting on boards. Since the siricid emergence was heavy, the Ibalia had evidently just emerged also, because their life cycles are closely coordinated. Dr. Daly visited the Donner Burn in July 1962 and reported many Rhyssa and Megarhyssa flying and ovipositing on dead trees. Siricid flights were also heavy at this time.[4/] The Hat Creek rearings of material from the two burns produced Ibalia adults but no Rhyssa or Megarhyssa. Chrystal and Myers (1928) found that Ibalia leucospoides Hochenw. has a 3-year life cycle in England, but the California species apparently has a 2-year life cycle.

Parasites must play a very important role in reducing siricid populations. Chrystal and Myers (1928), Hanson (1939), and Rawlings (1951) have all recognized the importance of Ibalia and Rhyssa parasites for controlling siricids. In 1929 the introduction of Rhyssa, an ectoparasite, was started in New Zealand where Sirex noctilio F. is a primary pest of Monterey pine. The introduced Rhyssa was successful enough to begin importing the endoparasite, Ibalia, from America and England in 1949. Ibalia parasitizes very young larvae by ovipositing through the siricid oviposition borings, while Rhyssa and Megarhyssa parasitize larger late-instar larvae by drilling directly through the wood to reach them. Thus the two types of parasites do not compete directly with each other.

Blackbirds, bluebirds, sparrows, and woodpeckers were also numerous around the Hughes Brothers mill on September 27. They were feeding on siricids and parasites. They ate the soft abdomen and left head and thorax. Woodpeckers were working on stacked, infested lumber, apparently after larvae or newly emerging adults.

4/ Verbal communication with the author.

The importance of birds as predators is unknown. Both Hanson (1939) and Chrystal (1928) state that birds seem to leave siricid adults alone and woodpeckers feed on them only upon chance encounter in the wood. But personal observations, and those of mill owners and workers, refute that statement in California. Large numbers of birds were attracted to stacks of infested lumber where there were concentrations of siricids. However, their control effect may have been nullified because of their apparent indiscriminate feeding on Ibalia parasites as well as siricids.

Literature Cited

Badun, S.
1959. Application of radioactive isotopes in wood technology. Drvna industrija, 10 (5/6), 86.

Berryman, A. A.
1961. Radiographic techniques for the detection, sampling and biological studies of forest insects. M. Sci. Thesis, 40 pp., illus. Univ. of Calif., Berkeley.

_______________, and Stark, R. W.
1962. Radiography in forest entomology. Ann. Ent. Soc. Amer. 55(4): 456-466, illus.

Bletchly, J. D.
1961. The effect of gamma-radiation on some wood-boring insects. Ann. Appl. Biol. 49: 362-370.

Chrystal, R. N.
1928. The Sirex woodwasps and their importance in forestry. Bull. Ent. Res. 19: 219-247.

_______________, and Myers, J. G.
1928. Natural enemies of Sirex cyaneus Fab., in England and their life history. Bull. Ent. Res. 49: 67-77.

Crisp, D. J. and Jones, L. W. G. and Watson, W.
1953. Use of X-ray stereoscopy for examining shipworm infestation in vivo. Nature 172: 408-409, illus.

DeMars, Clarence J., Jr.
1962. A comparison of X-ray analysis and bark dissection in sampling the western pine beetle. Submitted to the Can. Ent. for publication.

Eastman Kodak Company
1960. The fundamentals of radiography. 76 pages, illus.

Fisher, R. C., and Tasker, H. S.
1940. The detection of wood-boring insects by means of X-rays. Ann. Appl. Biol. 27: 92-100.

Gardiner, L. M.
1957. Collecting wood-boring beetle adults by turpentine and smoke. Can. Dept. Agr., Div. For. Biol., Bi-mo. Rept., 13(1): 2.

Hanson, H. S.
1939. Ecological notes on the Sirex woodwasps and their parasites. Bull. Ent. Res. 30: 27-65.

Johnson, N. E., and Molatore, H. D.
1961. X-ray detection of Douglas-fir beetles reared in slabs. Canad. Ent. 93(10): 928-931, illus.

Linsley, E. G.
1933. Some observations of the swarming of Melanophila. Pan. Pac. Ent. 9: 138.

Middlekauff, W. W.
1960. The siricid woodwasps of California. Bull. Calif. Insect Survey 6(4): 59-77, illus.

____
1962. Notes and description of the previously unknown male of Sirex longicauda Middlekauff (Hymenoptera: Siricidae). Pan. Pac. Ent. 38(1): 31-32.

Oliver, A. C.
1959. Use of X-rays in the detection of Teredo in wood. Jour. Inst. Wood Sci. 3: 47-52, illus.

Peterson, Alvah
1937. Entomological equipment and methods, Part Two. John S. Swift Co. Inc., 334 pp., illus.

Rawlings, G. B.
1951. The establishment of Ibalia leucospoides in New Zealand. Forest Research Institute, New Zealand Forest Service. Forest Res. Notes 1(3): 14 pp.

Wilson, L. F.
1962. Insect damage to field-piled pulpwood in northern Minnesota. Jour. Econ. Ent. 55(4): 510-516, illus.

APPENDIX

Table A.--Comparison of siricids found by radiographs and board dissection. (Radiographs not used for reference during dissection.)

Board	Radiographs											Board dissection										
	Larvae		Pupae		Adults		Unknowns		Total		Total	Larvae		Pupae		Adults		Unknowns		Total		Total
No.	A	D	A	D	A	D	A	D	A	D	A + D	A	D	A	D	A	D	A	D	A	D	A + D
1	2	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	2	0	0	0	0	0	0	0	2	0	2	1	1	0	0	0	0	0	0	1	1	2
4	1	1	0	0	0	0	0	0	1	1	2	0	1	0	0	0	0	0	0	0	1	1
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	1	1
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	1	0	0	0	0	0	0	1	1	2	1	1	0	0	0	0	0	0	1	1	2
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	2	0	0	0	0	0	0	0	2	0	2	2	0	0	0	0	0	0	0	2	0	2
12	4	1	0	0	0	0	0	0	4	1	5	0	0	0	0	0	0	0	0	0	0	0
13	0	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	1	1
14	2	0	0	0	0	0	0	0	2	0	2	2	0	0	0	0	0	0	0	2	0	2
15	4	0	0	0	0	0	1	0	5	0	5	4	0	0	0	0	0	1	0	5	0	5
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	1	0	1
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	6	1	0	0	0	0	1	0	7	1	8	6	1	0	0	0	0	1	0	7	1	8
Totals	25	6	0	0	0	0	2	0	27	6	33	17	6	0	0	0	0	2	0	19	6	25

Table B.--Comparison of siricids found by radiographs and board dissection.
(Radiographs used for reference during dissection.)

Board	Radiographs											Board dissection and radiographs										
	Larvae		Pupae		Adults		Other		Total		Total	Larvae		Pupae		Adults		Other		Total		Total
No.	A	D	A	D	A	D	A	D	A	D	A + D	A	D	A	D	A	D	A	D	A	D	A + D
1	0	0	0	0	0	0	3	1	3	1	4	0	0	0	0	0	0	0	3	0	3	3
2	0	0	0	0	0	0	1	1	1	1	2	0	1	0	0	0	0	1	0	1	1	2
3	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	1	0	1
4	0	0	0	0	0	0	3	1	3	1	4	0	0	0	0	0	0	3	0	3	0	3
5	4	0	0	0	0	0	0	0	4	0	4	3	1	0	0	0	0	0	0	3	1	4
6	7	0	0	0	0	0	4	0	11	0	11	6	1	0	0	0	0	4	0	10	1	11
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	2	0	0	0	0	0	0	0	2	0	2	2	0	0	0	0	0	0	0	2	0	2
10	2	0	0	0	0	0	1	0	3	0	3	1	2	0	0	0	0	0	0	1	2	3
11	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
12	2	0	0	0	0	0	0	0	2	0	2	2	0	0	0	0	0	0	0	2	0	2
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	1	0	1
15	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	1	0	1	0	1
16	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	1	0	1
17	2	0	0	0	0	0	0	0	2	0	2	2	0	0	0	0	0	0	0	2	0	2
18	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	1	0	0	0	1	1
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1	0	0	1	0	0	0	0	1	1	2	1	0	0	0	0	0	0	0	1	0	1
Totals	23	0	0	1	0	1	13	3	36	6	42	19	5	0	0	0	1	10	3	29	9	38

COLLECTION RECORDS FOR IBM DATA PROCESSING

Insects in Burned Timber

ate Burned ____/____

urn No. ________

ounty ________

levation ________

opography ________

spect ________

ajor Type ________

tand-size Class ________

Stocking ________

Acres Burned ________

Intensity of Burn ________

Salvage:

Date started ____/____

Months to comp. ________

Percent salvaged ________

Date: ________

Collector: ________

Remarks: ________

Host					Insect												
pe	D.b.h.	Position	No. attacks/ sq. ft.	Diameter log sec.	Height on host	Aspect on host	Depth of boring	Where found	Serial number	Date collected Mo.	Day	Year	Family	Genus	Species	Sex	Stage